

# New clues to the evolution of dwarf early-type galaxies

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## ABSTRACT

Surface photometry of 18 Virgo cluster dwarf elliptical (dE) and dwarf lenticular (dS0) galaxies, made by Gavazzi et al. (2001) in the H-band ( $1.65\ \mu\text{m}$ ) and in the B-band ( $0.44\ \mu\text{m}$ ), shows that the ratio of the effective radii of these stellar systems in the B- and H-band,  $r_{eB}/r_{eH}$ , ranges between 0.7 and 2.2. In particular, dwarf ellipticals and lenticulars with a red total color index B–H (i.e. with  $3.2 < \text{B–H} < 4$ ) have equal effective radii in these two pass-bands. By contrast, blue (i.e. with  $2.5 < \text{B–H} < 3.1$ ) dEs and dS0s have B-band effective radii about 50% longer than the H-band ones, on average. Consistently, strong negative gradients in B–H along the galactocentric radius are found to be associated with blue total colors. This trend is not found in a sample of 29 giant E and S0 galaxies of the Coma cluster with analogous data available in the literature. These early-type giants span a broad range in  $r_{eB}/r_{eH}$  (0.2–2.2), with a mean  $r_{eB}/r_{eH} \sim 1.1$ , but a narrow range in (red) color ( $3.3 < \text{B–H} < 4.2$ ). In these stellar systems, color gradients are usually interpreted as due either to age/metallicity gradients along the radial coordinate or to dust attenuation, whatever the total color of the system is. Assuming each of these three distinct interpretations of the origin of color gradients, we discuss the origin of the association of strong negative color gradients with blue colors found in the early-type dwarfs under study, in relation with current scenarios of formation and evolution of dE and dS0 galaxies.

**Key words:** galaxies: evolution - galaxies: structure - galaxies: elliptical and lenticular, cD - galaxies: fundamental parameters

## 1 INTRODUCTION

Dwarf elliptical (dE) and dwarf lenticular (dS0) galaxies are the most common galaxies in the local universe, as discovered by the earliest studies of nearby clusters, such as Virgo (Binggeli, Sandage & Tammann 1985; Sandage, Binggeli & Tammann 1985) and Fornax (Ferguson & Sandage 1988; Ferguson 1989). Nonetheless, their origin (e.g. White & Frenk 1991; Ostriker 1993; Babul & Rees 1992; Koo et al. 1995, 1997; Mao & Mo 1998; Moore, Lake & Katz 1998; Moore et al. 1999; Lin & Faber 1983) is still matter of uncertainty (e.g. Conselice, Gallagher & Wyse 2001; Drinkwater et al. 2001). An exponential light distribution seems to be characteristic of early-type dwarfs, though not ubiquitous, both in the optical (Faber & Lin 1983) and in the near-IR (James 1991, 1994). However, it is still matter of debate whether this stellar disk-component is rotationally flattened or not (e.g. Rix, Carollo & Freeman 1999; Geha, Guhathakurta & van der Marel 2001).

As a latest result of their extensive observational campaign centered on H-band ( $1.65\ \mu\text{m}$ ) imaging of about 1200 nearby giant and dwarf early- and late-type galaxies, Gavazzi and collaborators (Gavazzi et al. 2000, 2001) have found that the decomposition of the H-band surface bright-

ness profile of a galaxy is a strong function of its total H-band luminosity, whatever the Hubble classification of the galaxy is. In fact, the fraction of exponential-disk law (Freeman 1970) decompositions decreases with increasing luminosity of the galaxy, while the fraction of bulge+disk decompositions increases with luminosity. In particular, pure de Vaucouleurs-law (de Vaucouleurs 1948) profiles are absent at near-IR luminosities lower than  $10^{10}\ L_{\odot}$ . In this regime, Gavazzi et al. (2001) find that dwarf-elliptical peculiar (pec) galaxies have structural parameters indistinguishable from those of late-type dwarfs and, therefore, propose that dE pec galaxies represent the missing link between dEs and dwarf irregulars (dIs).

Though the presence of an exponential-disk component in dE, dS0 and dI galaxies, in general, may point to similarities between the formation and evolution processes of these three types of dwarf galaxies, only the late-type galaxies are definitely held to be HI-rich (e.g. Boselli et al. 2001). In fact, there is recent evidence that some dE galaxies are associated with atomic gas, but HI gas and stars may not always be parts of the same dynamical system (e.g. Young & Lo 1997). Atomic gas plays a fundamental role in the formation and evolution of exponential-disks (e.g. Dalcanton, Spergel

& Summers 1997; Boissier & Prantzos 2000; Ferguson & Clarke 2001). As reviewed by the latter authors, the origin of stellar exponential-disks finds a natural explanation in viscosity-driven radial flows, under the assumption that the star formation and viscous timescales are comparable. Assuming this simultaneity, the exponential-disk scale-length is found either to increase with time, if the cosmologically-motivated gaseous infall is concurrent with the previous two processes, or to stay constant if the bulk of the disk is assembled before star formation and viscosity act in a significant manner (Ferguson & Clarke 2001). In the former case, successive stellar populations trace the settling of the newly infalling gas at different disk ages. As a straightforward consequence, a radial color gradient is produced and the exponential-disk scale-lengths are expected to be larger in the optical pass-bands than in the near-IR ones.

However, not only disk-galaxies but also disk-less galaxies may show a wavelength-dependence of their characteristic scale-length (e.g. the effective radius, i.e. the radius which contains 50% of the total luminosity), simply as a result of the well-known effects of age and metallicity on broad-band colors of stellar populations (e.g. Bruzual & Charlot 1993; Worthey 1994). In fact, color gradients along the radial coordinate of a galaxy may be due either to a gradient in age (with fixed metallicity) or to a gradient in metallicity (with fixed age) of its stellar populations (e.g. Peletier, Valentijn & Jameson 1990; Tamura et al. 2000; Saglia et al. 2000; de Jong 1996), whatever the causes of these gradients are. Furthermore, dust attenuation toward the galaxy center is able to reproduce differences in the observed radial surface brightness distribution at two wavelengths (e.g. in the optical and near-IR), due to the difference in optical depth at these two wavelengths for a given dust column density, even under the hypothesis that a simple stellar population is present, and without introducing a significant change in the observed total color (Witt, Thronson & Capuano 1992).

In order to investigate the presence of color gradients and their origin (if any) in early-type dwarfs, here we study the relationships (if any) between different photometric parameters (effective radius  $r_e$ , bulge-to-total luminosity ratio  $B/T$ , total optical-near-IR color index  $B-H$  and  $B-H$  color profile) of 18 Virgo cluster dE and dS0 galaxies, imaged by Gavazzi et al. (2001) in the B-band ( $0.44 \mu\text{m}$ ) and H-band. This sample comprises objects one to a few magnitudes brighter than dwarf elliptical and spheroidal galaxies seen in the Local Group (e.g. Mateo 1998), which form a different population of early-type dwarfs (e.g. Conselice, Gallagher & Wyse 2001 and references therein), as witnessed also by their different photometric parameters.

## 2 THE SAMPLE

B- ( $0.44 \mu\text{m}$ ), V- ( $0.55 \mu\text{m}$ ) and H-band ( $1.65 \mu\text{m}$ ) surface photometry of 17 dwarf elliptical and lenticular galaxies plus 1 low-mass E pec/S0 galaxy was obtained by Gavazzi et al. (2001 – hereafter referred to as G01). These objects, with photographic magnitude  $m_p \leq 16.0$ , were selected from the Virgo Cluster Catalogue (VCC) of Binggeli, Sandage & Tammann (1985). With the exception of VCC 1078, they are all certain members of the cluster, where membership was assigned by Binggeli, Sandage & Tammann and Binggeli,

**Figure 1.** Projected spatial distribution of the 18 VCC early-type dwarfs listed in Tab. 1 on to the sky-region occupied by the Virgo cluster. We indicate the position of the maximum projected galaxy density of cluster A (containing M 87), of M 87 and of the centre of cluster B (containing M 49) as given by Binggeli, Tammann & Sandage (1987), as well as the sky-regions defined as the Southern Extension, M and W Clouds (see Binggeli, Tammann & Sandage). Furthermore, we draw the circle of 4 degrees radius centred on the centre of Cluster A, the circle of 2 degrees radius centred on M 87 and the circle of 1.5 degrees radius centred on the centre of Cluster B.

Popescu & Tammann (1993). Hereafter we refer to these 18 dwarf/low-mass early-type galaxies as the VCC early-type dwarf sample.

Fig. 1 gives a pictorial view of the projected spatial distribution of these galaxies on to the sky-region occupied by the Virgo cluster. It shows that the dwarfs under study lay either within a projected radial distance of 2 degrees from M 87 (associated with cluster A), with the exception of VCC 608 (laying in the corona between the previous region and a circle of 4 degrees radius centred on the maximum projected galaxy density of cluster A), or within a projected radial distance of 1.5 degrees from the centre of cluster B (see Binggeli, Tammann & Sandage 1987 for the definitions of clusters A and B). The 3D structure of the Virgo cluster

**Table 1.** Catalogue parameters of the Virgo cluster early-type dwarfs.

VCC Den.	NGC/IC Den.	RA(1950.0) hh mm ss	Dec(1950.0) ° ' "	Hubble type	log D	log R	v km s <sup>-1</sup>
608	NGC 4323	12 20 29.70	16 10 58.0	dE4,N	1.16	0.30	1803
745	NGC 4366	12 22 14.40	07 37 48.0	dE6,N	1.03	0.38	1286
786	IC 3305	12 22 43.80	12 07 54.0	dE7,N	1.32	0.58	2388
951	IC 3358	12 24 22.20	11 56 42.0	dE2,N pec/dS0(2),N	1.28	0.18	2066
965	IC 3363	12 24 31.20	12 50 06.0	dE7,N	1.26	0.52	790
1036	NGC 4436	12 25 10.20	12 35 30.0	dE6/dS0(6),N	1.33	0.38	1163
1073	IC 794	12 25 36.50	12 22 11.0	dE3,N	1.26	0.12	1899
1078		12 25 39.00	10 02 24.0	dE5 pec?	0.86	0.30	
1122	IC 3393	12 26 09.60	13 11 30.0	dE7,N	1.30	0.64	436
1173		12 26 43.00	13 15 16.0	dE5,N	0.80	0.29	2468
1254	NGC 4472	12 27 32.80	08 21 03.0	dE0,N	0.82	0.00	1350
1308	IC 3437	12 28 14.40	11 37 00.0	dE6,N	1.10	0.45	1721
1348	IC 3443	12 28 43.90	12 36 28.0	dE0,N pec	0.77	0.00	1679
1386	IC 3457	12 29 19.20	12 56 00.0	dE3,N	1.17	0.22	1426
1453	IC 3478	12 30 12.80	14 28 19.0	dE2,N	1.21	0.11	1949
1491	IC 3486	12 30 42.40	13 08 00.0	dE2,N	0.86	0.12	903
1499	IC 3492	12 30 48.20	13 07 44.0	E3 pec/S0	0.80	0.15	
1684	IC 3578	12 34 07.80	11 22 42.0	dS0(8)	1.10	0.54	

is complex (e.g. de Vaucouleurs 1961). According to Gavazzi et al. (1999), the distance modulus  $\mu_0$  of cluster A is  $30.84 \pm 0.06$ , while, for cluster B, dominated by M 49,  $\mu_0 = 31.84 \pm 0.10$ . As a consequence, the galaxies associated with cluster B are 60% farther from us than those associated with cluster A. For the purposes of the present analysis, we assume that all the 18 VCC galaxies under study lay at a distance of 17.0 Mpc to us, in agreement with G01.

The VCC early-type dwarf sample contains 13 dE,N galaxies, 1 dE,N/dS0,N galaxy and 1 dE/dS0,N galaxy, where N stands for “nucleated”. Such a high fraction of nucleated dwarf ellipticals reflects the fact that dE,N galaxies are more luminous than non-nucleated dwarf ellipticals and, therefore, their fraction increases in a magnitude-limited sample such as the G01 one. It is also straightforward to understand that dE,Ns are the easiest to detect at both optical and near-IR pass-bands among dEs. Though there are different possibilities of producing nucleation, Conselice, Gallagher & Wyse (2001) conclude that dEs and dE,Ns within 6 degrees from the centre of Virgo cluster A and with heliocentric radial velocity  $v < 2400 \text{ km s}^{-1}$  have similar origins, since the velocity characteristics of these two populations are not significantly different. In particular, these authors list heliocentric radial velocities for 15 out of the 18 galaxies of the VCC early-type dwarf sample. Relying on their result, we assume that all the 18 galaxies under study have the same origin.

In Tab. 1, we list the VCC catalogue properties and the heliocentric radial velocities (Conselice, Gallagher & Wyse 2001) of the individual galaxies relevant to this study, as follows:

Col. 1: the galaxy denomination;  
 Col. 2: alternate (NGC/IC) galaxy denomination;  
 Col. 3,4: celestial coordinates (RA and Dec, respectively) at the Equinox B1950;  
 Col. 5: the morphological classification;  
 Col. 6: decimal logarithm of the major-axis diameter D measured on the du Pont plates at the faintest detectable isophote (in units of  $0.1'$ );

Col. 7: estimated major-to-minor axis ratio R, measured analogously to D;

Col. 8: the heliocentric radial velocity.

We refer the reader to G01 for details concerning observations, data reduction, photometric calibration and image reduction procedures of the 18 VCC galaxies under study. For the present analysis it is important to say that these authors derived azimuthally averaged surface brightness profiles, that were fitted using either a de Vaucouleurs  $r^{1/4}$  law, an exponential-law, a bulge+disk model or an exponential/de Vaucouleurs truncated model. In particular, the total magnitude of each galaxy was obtained by adding to the flux measured within the outermost significant isophote the flux extrapolated to infinity along the model that fitted the outer parts of the galaxy. The effective radius  $r_e$  and the effective surface brightness  $\mu_e$  (i.e. the mean surface brightness within  $r_e$ ) of each galaxy were computed in two ways (Gavazzi et al. 2000). The “fitted” values of the individual components were derived from the individual fitted profiles, extrapolated to zero and to infinity. By contrast, the “empirical” values of the effective radius and surface brightness of the system were obtained locating the half-light point along the observed light profile, where the total amount of light is given by the total magnitude described above, and corrected for seeing according to Saglia, Bender & Dressler (1993). The “empirical” values of  $r_e$  determined by G01 are used here. Finally, the G01 determined the bulge-to-total luminosity ratio of individual galaxies as a result of the fitting procedure.

Tab. 2 contains the H- and B-band photometric properties of individual galaxies listed in G01 and relevant to this study, as follows:

Col. 1: the galaxy denomination in the VCC;  
 Col. 2: the H-band bulge effective radius  $r_{ebfH}$ ;  
 Col. 3: the H-band disk effective radius  $r_{edfH}$ ;  
 Col. 4: the H-band effective radius  $r_{eH}$  and its error;  
 Col. 5: the classification according to the H-band profile decomposition (1 = de Vaucouleurs-law, 2 = bulge+disk system, 3 = exponential-law, 4 = exponential/de Vaucouleurs

**Table 2.** Photometric parameters of the Virgo cluster early-type dwarfs.

VCC Den.	$r_{\text{ebfH}}$ "	$r_{\text{edfH}}$ "	$r_{\text{eH}}$ "	cl.	$B/T_H$	$r_{\text{ebfB}}$ "	$r_{\text{edfB}}$ "	$r_{\text{eB}}$ "	cl.	$B/T_B$	H mag	B mag
608		17.26	$17.7 \pm 1.1$	3	0.00		16.47	$15.7 \pm 1.2$	3	0.00	$11.87 \pm 0.06$	$15.29 \pm 0.07$
745	8.99		$8.8 \pm 1.1$	1	1.00	6.53	24.36	$16.3 \pm 1.4$	2	0.29	$11.99 \pm 0.06$	$14.95 \pm 0.06$
786		16.20	$15.6 \pm 1.4$	3	0.00	10.25	32.13	$27.8 \pm 3.0$	2	0.29	$12.21 \pm 0.06$	$14.84 \pm 0.11$
951	3.99	18.33	$17.2 \pm 1.3$	2	0.04	6.63	25.85	$21.1 \pm 1.6$	2	0.26	$11.60 \pm 0.06$	$14.46 \pm 0.07$
965	1.83	29.34	$30.1 \pm 7.9$	2	0.01	0.92	21.67	$23.0 \pm 1.4$	2	0.01	$11.66 \pm 0.31$	$15.54 \pm 0.06$
1036	7.98	30.02	$18.5 \pm 1.5$	2	0.36	7.82	31.01	$21.6 \pm 1.6$	2	0.28	$10.65 \pm 0.06$	$14.06 \pm 0.06$
1073	2.77	12.30	$10.8 \pm 1.1$	2	0.11	5.14	26.09	$24.6 \pm 1.5$	2	0.20	$11.41 \pm 0.06$	$14.48 \pm 0.06$
1078		11.44	$11.7 \pm 1.1$	3	0.00		12.73	$12.2 \pm 1.1$	3	0.00	$13.37 \pm 0.06$	$16.01 \pm 0.06$
1122	12.37		$11.8 \pm 1.0$	1	1.00	9.05	28.88	$16.6 \pm 1.4$	2	0.43	$11.99 \pm 0.06$	$15.00 \pm 0.06$
1173		11.77	$12.1 \pm 1.1$	3	0.00		10.61	$11.3 \pm 1.1$	3	0.00	$13.20 \pm 0.06$	$16.43 \pm 0.06$
1254	0.93	13.02	$12.2 \pm 1.4$	2	0.05	1.44	13.02	$12.3 \pm 1.2$	2	0.22	$12.07 \pm 0.06$	$15.73 \pm 0.06$
1308	7.84		$7.5 \pm 1.0$	1	1.00	6.87	19.25	$11.1 \pm 1.2$	2	0.44	$12.73 \pm 0.06$	$15.75 \pm 0.07$
1348	1.19	8.26	$7.7 \pm 1.0$	2	0.06	1.79	9.58	$8.4 \pm 1.1$	2	0.09	$12.42 \pm 0.06$	$16.01 \pm 0.07$
1386	19.79		$20.9 \pm 1.2$	1	1.00	16.57	52.87	$34.7 \pm 4.0$	2	0.35	$12.07 \pm 0.06$	$14.82 \pm 0.10$
1453	3.07	10.86	$10.1 \pm 1.1$	2	0.10	4.79	20.40	$19.1 \pm 1.4$	2	0.18	$11.58 \pm 0.07$	$14.46 \pm 0.07$
1491	7.23	36.41	$15.1 \pm 5.1$	2	0.46	7.78	28.10	$13.3 \pm 1.3$	2	0.41	$11.64 \pm 0.20$	$15.26 \pm 0.07$
1499	7.21		$7.7 \pm 1.0$	1	1.00	4.92	12.67	$7.4 \pm 1.1$	2	0.64	$12.57 \pm 0.07$	$15.18 \pm 0.07$
1684	2.08	19.76	$20.6 \pm 1.1$	2	0.01	1.95	17.39	$20.3 \pm 1.5$	2	0.03	$12.64 \pm 0.06$	$15.46 \pm 0.06$

truncated model);

Col. 6: the H-band bulge-to-total luminosity ratio  $B/T_H$  (0.00 and 1.00 identify bulge-less and disk-less systems, respectively);

Col. 7: the B-band bulge effective radius  $r_{\text{ebfB}}$ ;

Col. 8: the B-band disk effective radius  $r_{\text{edfB}}$ ;

Col. 9: the B-band effective radius  $r_{\text{eB}}$  and its error;

Col. 10: the classification according to the B-band profile decomposition (see Col. 5);

Col. 11: the B-band bulge-to-total luminosity ratio  $B/T_B$  (see Col. 6);

Col. 12: the observed total H-band magnitude H and its error;

Col. 13: the observed total B-band magnitude B and its error.

We note that 5 objects (i.e.: VCC 745, 1122, 1308, 1386 and 1499) change classification from a de Vaucouleurs- to a bulge+disk system, and 1 object (VCC 786) changes its classification from an exponential-disk to a bulge+disk system, from the near-IR to the optical case. The B-band surface brightness profile of VCC 786 is decomposed into relatively extended and equally faint bulge- and disk-components (cf. G01), so that its profile fitting may be questionable but not its values of B and  $r_{\text{eB}}$ . In the case of VCC 1499, the H-band surface brightness profile extends up to 70% of the radial extension of its B-band photometry, so that the photometric parameters of this object are reliable. By contrast, for VCC 745, 1122, 1308 and 1386, the H-band surface brightness profiles extend only up to 30–50% of the radial extension of the B-band ones. For these 4 galaxies, it may be questioned that a faint, extended exponential-disk might not have been detected against the near-IR background (typically of  $20.5 \text{ H-mag arcsec}^{-2}$  in the images of these galaxies). If an exponential-disk component was indeed missed/misidentified by the near-IR observations, a best-fit de Vaucouleurs-law would underestimate the surface intensity in the outer regions of these systems. The visual inspection of the radial photometric profiles of VCC 745, 1122, 1308 and 1386 displayed in G01 suggests that the previous

systematic effect, if any, is not strong. We estimate that the H-band total magnitudes of these 4 galaxies, listed in Col. 11 of Tab. 2, may be under-luminous by  $\sim 0.2 \text{ mag}$ , while their values of  $r_{\text{eH}}$  may be underestimated by  $\sim 10\%$ . We anticipate that these potential systematic uncertainties do not bias our results (cf. Sect. 3).

In addition to these 18 VCC early-type dwarfs, we consider, as a comparison, a sample of 29 giant elliptical and lenticular galaxies of the Coma cluster, optically selected from the Catalogue of Galaxies and Clusters of Galaxies (CGCG) of Zwicky et al. (1961–1968) and observed in the H-band by Scodeggio et al. (1998 – hereafter referred to as S98). We adopt a distance from the Coma cluster to us of 96.0 Mpc from S98. The H-band data reduction and analysis of S98 is the same of G01, except that all the radial surface brightness profiles of the S98 galaxies were fitted with a de Vaucouleurs-law. These 29 CGCG early-type giants were observed in the B-band by different authors, listed in S98, adopting either photoelectric aperture photometry or CCD surface photometry, but their B-band photometric parameters were derived by Saglia, Bender & Dressler (1993) by fitting a de Vaucouleurs-law to the radial photometric profile derived from 2D data. Therefore, for these giants, only fitted effective radii are available. Both observed total H- and B-band magnitudes of these 29 galaxies come from G. Gavazzi (2001, private communication). These H-band total magnitudes were derived by S98 by adopting the same procedure of G01. By contrast, these B-band total magnitudes were either taken from the literature, if derived from surface photometry, or derived by Gavazzi & Boselli (1996) by applying the “growth curves” technique to the available photoelectric aperture measurements. Both H- and B-band total observed magnitudes have a typical uncertainty of 0.1 magnitude.

In Tab. 3, we list the properties of the 29 giant E and S0 galaxies under study relevant to this analysis, as follows:

Col. 1: the galaxy denomination;

Col. 2: alternate (NGC/IC) galaxy denomination;

Col. 3: the morphological classification;

**Table 3.** Characteristic parameters of 29 giant E and S0 galaxies of the Coma cluster.

CGCG Den.	NGC/IC Den.	Hubble type	$r_{eH}$ "	cl.	B/T <sub>H</sub>	$r_{eB}$ "	cl.	B/T <sub>B</sub>	H mag	B mag
160017	NGC 4807	S0 pec	7.53±0.99	1	1.00	8.95±2.70	1	1.00	10.69±0.1	14.56±0.1
160021	NGC 4816	S0	14.63±0.72	1	1.00	20.99±2.70	1	1.00	10.06±0.1	13.74±0.1
160028	NGC 4827	S0	10.28±0.70	1	1.00	13.87±2.41	1	1.00	10.37±0.1	14.10±0.1
160042	NGC 4840	S0	6.32±0.48	1	1.00	6.79±2.41	1	1.00	10.84±0.1	14.73±0.1
160063	NGC 4850	S0	3.66±0.69	1	1.00	4.81±2.41	1	1.00	11.54±0.1	15.22±0.1
160070	NGC 4854	S0	8.51±1.05	1	1.00	18.28±2.70	1	1.00	11.40±0.1	14.98±0.1
160103	NGC 4926	E	7.25±0.98	1	1.00	9.37±2.25	1	1.00	10.25±0.1	14.08±0.1
160130	NGC 4957	E	20.03±0.84	1	1.00	14.52±2.70	1	1.00	10.44±0.1	14.07±0.1
160215	NGC 4860	E	6.69±0.21	1	1.00	7.11±2.41	1	1.00	10.82±0.1	14.57±0.1
160217	IC 3957	E	2.16±0.51	1	1.00	4.81±2.30	1	1.00	11.95±0.1	15.50±0.1
160218	IC 3959	E	2.88±0.60	1	1.00	5.52±2.25	1	1.00	11.35±0.1	15.52±0.1
160220	IC 3963	S0	12.85±3.17	1	1.00	5.91±2.41	1	1.00	11.92±0.1	15.69±0.1
160221	NGC 4864	E	5.89±0.36	1	1.00	6.79±2.25	1	1.00	11.11±0.1	14.45±0.1
160222	NGC 4867	E	4.43±0.81	1	1.00	3.82±2.25	1	1.00	11.68±0.1	15.45±0.1
160229	NGC 4873	S0	9.95±0.80	1	1.00	6.64±2.41	1	1.00	11.66±0.1	15.41±0.1
160230	NGC 4872	S0	2.57±0.27	1	1.00	3.10±2.35	1	1.00	11.66±0.1	15.26±0.1
160234	NGC 4876	E	6.85±0.83	1	1.00	4.92±2.25	1	1.00	11.61±0.1	15.47±0.1
160237	NGC 4883	S0	7.89±0.79	1	1.00	6.05±2.41	1	1.00	11.51±0.1	15.35±0.1
160238	NGC 4881	E	5.96±0.60	1	1.00	9.59±2.25	1	1.00	10.89±0.1	14.61±0.1
160239	NGC 4882	E	12.28±1.01	1	1.00	9.16±2.30	1	1.00	11.52±0.1	15.22±0.1
160242	IC 4011	E	4.48±0.51	1	1.00	4.09±2.30	1	1.00	12.40±0.1	16.14±0.1
160244	IC 4012	E	2.47±0.14	1	1.00	3.03±2.41	1	1.00	11.91±0.1	15.89±0.1
160246	IC 4021	S0	2.13±0.44	1	1.00	3.48±2.41	1	1.00	11.82±0.1	15.92±0.1
160247	NGC 4894	S0	21.69±4.56	1	1.00	4.59±2.41	1	1.00	12.34±0.1	16.04±0.1
160250	IC 4026	S0	5.79±0.64	1	1.00	6.79±2.41	1	1.00	11.88±0.1	15.61±0.1
160253	NGC 4906	E	5.43±0.45	1	1.00	7.98±2.25	1	1.00	11.54±0.1	15.30±0.1
160254	IC 4041	S0	11.94±2.52	1	1.00	5.91±2.41	1	1.00	12.04±0.1	15.56±0.1
160256	IC 4045	E/S0	5.35±0.66	1	1.00	4.81±2.25	1	1.00	11.25±0.1	14.99±0.1
160259	IC 4051	E	15.60±0.72	1	1.00	11.53±2.25	1	1.00	10.78±0.1	14.40±0.1

Col. 4: the H-band effective radius  $r_{eH}$  and its error;

Col. 5: the classification according to the H-band profile decomposition (see Col. 5 of Tab. 2);

Col. 6: the H-band bulge-to-total luminosity ratio  $B/T_H$  (see Col. 6 of Tab. 2);

Col. 7: the B-band effective radius  $r_{eB}$  and its error;

Col. 8: the classification according to the B-band profile decomposition (see Col. 5 of Tab. 2);

Col. 9: the B-band bulge-to-total luminosity ratio  $B/T_B$  (see Col. 6 of Tab. 2);

Col. 10: the observed total H-band magnitude H and its error;

Col. 11: the observed total B-band magnitude B and its error.

Hereafter no correction for Galactic extinction in direction either of the Virgo cluster or of the Coma cluster will be applied to the B- and H-band magnitudes, since this correction is negligible for our purposes. No correction for internal extinction to the photometric parameters of individual galaxies will be applied either.

### 3 RESULTS

#### 3.1 Wavelength-dependence of the effective radius in early-type dwarfs

Fig. 2 shows the distribution of the 18 VCC early-type dwarfs listed in Tab. 1 in the plane defined by the decimal logarithm of the ratio of  $r_{eB}$  and  $r_{eH}$  ( $r_{eB}/r_{eH}$ ) and

by the total color index B–H. Individual galaxies are represented by empty circles, asterisks or filled circles if their surface brightness profile follows either a de Vaucouleurs-law, a bulge+disk decomposition, or an exponential-law (type 1, 2 or 3, respectively – cf. Sect. 2). In panels ‘a’ and ‘b’ objects are classified according to profile decomposition either in the H-band or in the B-band (cf. Tab. 2), respectively. Fig. 2 shows that:

- $r_{eB}/r_{eH}$  spans the broad range 0.7–2.2;
- 7 early-type dwarfs with a relatively red color (i.e. with  $3.2 < B-H < 4$ ), i.e. VCC 608, 965, 1036, 1173, 1254, 1348 and 1491, have an average value of  $r_{eB}/r_{eH}$  equal to 1 (with an rms dispersion of 0.21);
- 10 early-type dwarfs and 1 E pec/S0 galaxy with a blue color (i.e. with  $2.5 < B-H < 3.1$ ) have B-band effective radii about 50% longer than the H-band ones, on average (with an rms dispersion of 0.44);
- when removing the three objects with a blue central excess (G01), i.e. VCC 951, 1499 and 1684, and the dE pec? galaxy VCC 1078, the remaining subsample of 7 blue early-type dwarfs clusters around an average value of  $r_{eB}/r_{eH} = 1.75$  (with an rms dispersion of 0.35).

Blue and red objects seem to be separated by a kind of “gap” in Fig. 2. We are not able to trace the origin of this apparent gap back to the selection effects of the G01 sample; instead we discuss the hypothesis that this gap is an effect of data analysis. First, we note that the classification according to surface brightness profile decomposition does not change

**Figure 2.** Plot of the total color index B–H vs. the decimal logarithm of the ratio of the B-band effective radius ( $r_{eB}$ ) and the H-band effective radius ( $r_{eH}$ ),  $r_{eB}/r_{eH}$ , for the 18 VCC early-type dwarfs (see Tab. 2). Galaxies are identified according to either the H-band profile classification given in Col. 5 of Tab. 2 (a) or the B-band profile classification given in Col. 10 of Tab. 2 (b). In each panel, the 18 VCC early-type dwarfs are represented by empty circles, asterisks and filled circles if their surface brightness profile follows either a de Vaucouleurs-law, a bulge+disk decomposition, or an exponential-law (type 1, 2 or 3, respectively – cf. Sect. 2).

from the H-band to the B-band, for the 7 red early-type dwarfs. By contrast, 6 out of the 11 blue early-type dwarfs change their classification from the near-IR to the optical case. Among these 6 objects, VCC 745, 1122, 1308 and 1386 may rise the suspect of a missed/misidentified exponential-disk component (cf. Sect. 2). The values of  $r_{eH}$  of these 4 galaxies should be underestimated by 40–90% in order to erase the difference between  $r_{eH}$  and  $r_{eB}$ , while the correction of  $r_{eH}$  supported by inspection of the H-band photometric profiles (G01, their Fig. 4) is 10%. The magnitudes of these corrections (if due) may shift the distribution of the previous 4 galaxies toward smaller values of  $r_{eB}/r_{eH}$  and redder B–H colors, filling the apparent gap in Fig. 2, but

**Figure 3.** B–H vs.  $r_{eB}/r_{eH}$  for the 18 VCC early-type dwarfs, here classified according to the slope of their B–H (a) or B–V (b) color profiles (cf. G01, their Fig. 4). Empty squares, empty triangles, filled squares and sun symbols identify objects with negative, null, positive and complex color profile slopes, respectively.

do not weaken the trend seen there. Hereafter we do not consider this gap as a significant feature.

In order to investigate if the average increase of  $r_{eB}/r_{eH}$  with B–H consistently reflects the average behaviour of the B–H color gradient with the total B–H color, we reproduce the same plot of Fig. 2 in Fig. 3a, but by adopting a classification based on the slope of the B–H color profile. B–H and B–V color profiles of the dwarfs under study are determined and displayed by G01 (their Fig. 4). From the full extension of these profiles, we derive average gradients in B–H and in B–V, in order to verify if the signs of these two color gradients are consistent. In general they are, and, as expected, the strength of the B–V color gradient is much lower. Nonetheless, in Fig. 3b, we plot B–H vs.  $r_{eB}/r_{eH}$  for our dwarfs, but we adopt a classification based on the slope of the B–V color profile, if available.

Fig. 3a shows that, for 6 out of the 7 blue early-type dwarfs with average  $r_{eB}/r_{eH} = 1.75$ , B–H decreases at larger galactocentric distances. We estimate strengths of the

**Figure 4.** Plot of the bulge-to-total luminosity ratio, either in the H-band ( $B/T_H$ ) (a) or in the B-band ( $B/T_B$ ) (b) vs.  $r_{eB}/r_{eH}$  for the VCC early-type dwarf sample. Objects are classified according to their H-band surface brightness profile decomposition and their symbols are the same as in Fig. 2a.

B–H color gradient  $\Delta(B-H)/\Delta \log r$  equal to -0.92, -0.63, -0.60, -0.57, -0.37 and -0.33 mag dex<sup>-1</sup> for VCC 745, 1453, 1073, 1308, 786 and 1386, respectively. By contrast, out of the 7 red early-type dwarfs, only 2 object (VCC 1036 and 1491) have a negative slope of the B–H color profile, while 4 objects have no gradient in B–H and 1 object (VCC 1254) becomes redder toward its outer regions. For VCC 1036 and 1491, we estimate values of  $\Delta(B-H)/\Delta \log r$  equal to -0.33 and -0.20 mag dex<sup>-1</sup>, respectively, significantly smaller, in absolute value, than the average strength of  $\Delta(B-H)/\Delta \log r$  of the previous 6 blue early-type dwarfs. None of the 3 blue early-type dwarfs with a blue central excess (G01), has a negative B–H color gradient, so that the strong blue central excess seems a sufficient explanation to their low values of  $r_{eB}/r_{eH}$  within the subsample of blue early-type dwarfs. We conclude that stronger negative color gradients are necessarily associated with larger values of  $r_{eB}/r_{eH}$ . However, since there is no reason a priori why strong negative color gradients should be associated with

**Figure 5.** Plot of  $B/T_H$  (a) and  $B/T_B$  (b) vs. B–H for the 18 sample early-type dwarfs. Galaxies are classified according to their H-band surface brightness profile decomposition and their symbols are the same as in Fig. 2a.

blue colors, we conclude that the displacement of the average locus of the 7 blue early-type dwarfs without a blue central excess from that of the 7 red dEs and dS0s in Fig. 2 is a robust and interesting behaviour, though is only a  $2\sigma$  effect.

Whatever the classification in terms of profile decomposition is (e.g. in the H-band),  $r_{eB}/r_{eH}$  does not seem to depend on the bulge-to-total luminosity ratio, either in the H-band or in the B-band, as shown in Fig. 4a,b, respectively. Interestingly, among the 5 blue objects which show an exponential-disk component only in the B-band surface brightness profile, the highest value of  $B/T_B$  and the smaller value of  $r_{eB}/r_{eH}$  belong to the E pec/S0 galaxy VCC 1499. According to G01, the very blue continuum and strong Balmer absorption lines of this object are typical of E+A galaxies which have experienced an intense burst of star formation ended about 1–2 Gyrs ago (Poggianti & Barbaro 1996).

As well as  $r_{eB}/r_{eH}$ , B–H does not seem to depend on the bulge-to-total luminosity ratio, as shown in Fig. 5, where

**Figure 6.** B–H color–H-band magnitude relation of the 18 VCC early-type dwarfs (large filled squares) and of the 29 CGCG early-type giants of the Coma cluster listed in Tab. 3 (small empty squares). The solid line and the two short-dashed lines represent the mean (1.13) and the  $\pm 1\sigma$  limits of the distribution of  $r_{eB}/r_{eH}$  of the giants, respectively.

**Figure 7.**  $r_{eB}/r_{eH}$  vs. H-band magnitude for the 18 VCC early-type dwarfs (large filled squares) and for 29 early-type giants of the Coma cluster (small empty squares). The solid line and the two short-dashed lines represent the mean (1.13) and the  $\pm 1\sigma$  limits of the distribution of  $r_{eB}/r_{eH}$  of the giants, respectively.

we plot  $B/T_H$  vs. B–H (panel ‘a’) and  $B/T_B$  vs. B–H (panel ‘b’), the VCC galaxies being classified according to their H-band surface brightness profile decomposition (cf. Fig. 2a).

Both  $B/T_H$  and  $B/T_B$  are less than 0.5 for those galaxies with a confirmed exponential-disk component in both pass-bands, so that, in these galaxies, the stellar populations associated with the disk largely contribute to, if not dominate, the emission in the near-IR and optical. Finally, we note that  $B/T_H$  and  $B/T_B$  are to first order identical both for the 7 red early-type dwarfs and for the previous 6 blue early-type dwarfs.

### 3.2 Early-type galaxies: dwarfs vs. giants

In this section we investigate if the increase of  $r_{eB}/r_{eH}$  with B–H previously found in the early-type dwarfs has an anal-

ogy in giant E and S0 galaxies. The findings may cast some light to the origin of the trend illustrated in Fig. 2. As a comparison, we adopt the sample of 29 early-type giants of the Coma cluster listed in Tab. 3. Unfortunately, B–H or B–V color profiles of these giant galaxies are not available to us, so that we can not study the behaviour of total color, color gradient and  $r_{eB}/r_{eH}$  in these systems.

Given that the range of  $\sim 600$  in H-band luminosity (i.e. mass) spanned by early-type giants and dwarfs implies differences in structural, kinematical and photometric properties, first we display the distribution of early-type dwarfs and giants in the planes  $M_H$ –B–H (Fig. 6) and  $M_H$ – $r_{eB}/r_{eH}$  (Fig. 7). Each sample of galaxies spans a range of  $\sim 10$  in H-band luminosity (Fig. 6), but the early-type giants, plotted as small empty squares, span a narrow range in color ( $3.3 < B-H < 4.2$ ), which overlaps the range in B–H spanned by the red subsample of the early-type dwarfs, hereafter plot-

**Figure 8.** B–H vs.  $r_{eB}/r_{eH}$  for the 18 VCC early-type dwarfs (large filled squares) and for 29 early-type giants of the Coma cluster (small empty squares). The solid line and the two short-dashed lines represent the mean (1.13) and the  $\pm 1\sigma$  limits of the distribution of  $r_{eB}/r_{eH}$  of the giants, respectively.

ted as large filled squares. B–H colors bluer than 3.1 are found only in early-type dwarfs. Conversely, the early-type giants span a broad range in  $r_{eB}/r_{eH}$ , their  $r_{eB}/r_{eH}$  ranging from  $\sim 0.2$  to  $\sim 2.2$ , with a mean value equal to 1.13 and an rms dispersion of 0.48 (cf. Fig. 7). Such a broad range, due in part to the non-homogeneous source of the photometric parameters of the giants (cf. Sect. 2), embraces the distribution of the early-type dwarfs at the  $2\sigma$  level. No trend of  $r_{eB}/r_{eH}$  with H-band magnitude is found, either overall or within each sample.

Finally, we reproduce the distribution of the early-type giants and dwarfs in the  $r_{eB}/r_{eH}$ –B–H plane in Fig. 8, where the solid line and the two short-dashed lines represent the mean (1.13) and the  $\pm 1\sigma$  limits of the distribution of  $r_{eB}/r_{eH}$  of the giants, respectively. Fig. 8 shows that the trend of increasing  $r_{eB}/r_{eH}$  with bluer B–H, found for dwarf systems, is not reproduced in the case of giant systems. This result, if not due to the larger uncertainties affecting the photometric quantities of the early-type giants under study, points to the conclusion that the wavelength-dependence of the effective radius of these stellar systems either has various origins or is due to a cause which does not modify the total color in a consistent, detectable manner.

The solid line representing the mean value of  $r_{eB}/r_{eH}$  of the giants (1.13) bisects the distribution of the dwarfs: 6 out of the 7 red dwarfs have  $r_{eB}/r_{eH}$  lower than 1.13 and, vice-versa, 8 out of the 11 blue dwarfs have  $r_{eB}/r_{eH}$  larger than 1.13. Moreover, giant E and S0 galaxies and blue early-type dwarfs show maximum values of  $r_{eB}/r_{eH} \sim 2.2$ , despite

the difference in their colors. Is therefore the trend claimed for the dwarfs a spurious result? A definitive answer to this question may come only from an analogous study based on larger statistics. Here we note that a relation between total colors and sign and strength of color gradients, as suggested for the early-type dwarfs under study (cf. Sect. 3.1), is an intriguing result and its existence is consistent with some scenarios of dwarf galaxy formation and evolution, as discussed next.

#### 4 THREE DIFFERENT INTERPRETATIONS

The increase of  $r_{eB}/r_{eH}$  in blue early-type dwarfs (Fig. 2) reflects the existence of a (strong) negative gradient in B–H and in B–V along the radial coordinate (Fig. 3). The data show that this is a necessary but not sufficient condition however. This trend is not found in giant E and S0 galaxies, which span a broad range in  $r_{eB}/r_{eH}$ , though their B–H color is almost as red as in red early-type dwarfs. Radial color gradients observed in individual giant elliptical and lenticular galaxies are commonly interpreted as a product either of age/metallicity gradients of the stellar populations along the radial coordinate or of dust attenuation (cf. Sect. 1). These interpretations do not imply a correlation between  $r_{eB}/r_{eH}$  and B–H.

In the following sections, these three theoretical interpretations will be extended to our results for early-type dwarfs and discussed individually, in relation with some scenarios of early-type dwarf galaxy formation and evolution

which may justify the trend seen in Fig. 2. The lack of data does not allow us to achieve a direct proof of the validity of any of these three interpretations. Moreover, the absence of a one-to-one correlation between  $r_{eB}/r_{eH}$  and the strength of the gradient in B–H, if not due to errors in data analysis, may indicate that the interpretation of Fig. 2 is complex.

#### 4.1 Age gradients

The integrated broad-band colors of E and S0 galaxies become progressively bluer toward fainter magnitudes (Faber 1973; see however Scodeggio 2001). This correlation, known as the color–magnitude relation, is universal and very tight in the optical for ellipticals and lenticulars in clusters at  $z=0$  (Bower, Lucey & Ellis 1992a,b). Relying on the commonly accepted interpretation of the color–magnitude relation (Kodama & Arimoto 1997), we conclude that, in blue early-type dwarfs, either the average metallicity is lower than in red early-type dwarfs of the same H-band luminosity or star formation is still going on. Here we make the hypothesis that the blue colors of the VCC sample dwarfs are due to the presence of a young stellar population. This hypothesis is supported by spectroscopy (G01) for some individual sample galaxies and is consistent with the results of Terlevich et al. (1999).

Fig. 5b shows that most of the B-band emission of the dwarfs is contributed by the stellar populations distributed within an exponential-disk component. This disk-component, if present, is also responsible for more than 50% of the total H-band luminosity (Fig. 5a). If we make the assumption that early-type dwarfs are rotationally flattened (cf. Sect. 1), the wavelength-dependence of their effective radius, and the relation between total color and sign and strength of the color gradients may be understood as effects of disk evolution. In this scenario, an increase of  $r_{eB}/r_{eH}$  happens in objects with on-going star formation activity, when the star formation, viscous and gaseous infall timescales are comparable (cf. Sect. 1). By contrast, the effective radius is not expected to change with wavelength in objects where either the bulk of the disk (and of the system) is assembled before star formation and viscosity act in a significant manner or star formation has ceased. Therefore, the objects with  $r_{eB}/r_{eH} \sim 1$  are expected to have red colors, as we find.

If red and blue early-type dwarfs belong to the same population (cf. Sect. 1), the former should be quiescent since more than 1–2 Gyrs, in order to justify the difference in colors between e.g. VCC 1491 and 1499 (G01). This quiescence may be due either to a relatively shorter star formation timescale or to an early interruption of the gaseous infall, due to phenomena like galactic winds, tidal stripping or ram-pressure by the intergalactic medium (IGM). There are no detections of HI gas for the VCC early-type dwarfs under study, but only upper limits to the observed HI flux for VCC 1254 and 1499 (Huchtmeier and Richter 1986), VCC 951 and 1491 (van Driel et al. 2000). Interestingly, increasing upper limits are associated with bluer objects. No trend between color and kinematic distribution is found for the 15 objects with measured heliocentric velocities. Beside this, Fig. 1 shows that all the early-type dwarfs of our sample but VCC 608 lay in dense regions of the Virgo cluster. These findings disfavour a key-role of IGM ram-pressure. On the

other hand, we note that the fraction of dE and dS0 galaxies with at least one giant galaxy within a projected distance of 15 arcmin (equivalent to  $\sim 75$  kpc at the assumed distance of Virgo) drops from 57% to 18%, when the red and blue subsamples are considered separately, respectively. This seems to favour tidal stripping as a mechanism of gas removal in the red VCC early-type dwarfs. Conversely, gas infall may sometimes trigger bursts of star formation in the nuclear regions of a galaxy (e.g. VCC 1499). The associated increase in blue luminosity in this central region may eventually erase differences between optical and near-IR effective radii.

#### 4.2 Metallicity gradients

The distribution in Fig. 2 may be explained by different strengths of a metallicity gradient along the radial coordinate in individual stellar systems with an assumed single-age stellar population (e.g. Bruzual & Charlot 1993; Worthey 1994). Such an interpretation has been invoked by Peletier, Valentijn & Jameson (1990) and more recently by Tamura et al. (2000) and Saglia et al. (2000) for (giant) elliptical galaxies. For the sake of correctness, we say that metallicity gradients are the currently most widely accepted interpretation of the existence of color gradients in such systems. On the other hand, we note that no correlation between color gradients and e.g.  $Mg_2$  gradients has been found so far, though only a small number of elliptical galaxies has been studied both for color gradient and  $Mg_2$  gradient (Peletier 1989). Reasons are discussed by Kobayashi & Arimoto (1999).

Unfortunately, there is no information about the content and radial distribution of metallicity of the early-type dwarfs under study, but we may gain some understanding from the giants. In fact, 14 out of the 29 giant E and S0 galaxies have radial profiles of line indices like  $Mg_2$  thanks to the spatially resolved spectroscopy of Mehlert et al. (2000). Twelve of these galaxies have negative  $Mg_2$  line-strength gradients: their colors and values of  $r_{eB}/r_{eH}$  are consistent with those of the rest of the giants. If taken as a face value, the mean  $r_{eB}/r_{eH} = 1.13$  obtained for the early-type giants indicates that metallicity gradients may increase  $r_{eB}$  by 10–15% with respect to  $r_{eH}$ . May the larger (up to 75% on average) effect on  $r_{eB}/r_{eH}$  seen for 7 blue early-type dwarfs be due to stronger metallicity gradients in these galaxies? A basic assumption to producing color and line-strength gradients in elliptical galaxies is that galactic winds blow later in the inner part of a galaxy because of a deeper potential well, defined mainly by dark matter (Martinelli, Matteucci & Colafrancesco 1998). However, efforts of fully reproducing observed color and line-strength gradients failed so far (Tantalo et al. 1998), so that some important physics seems to be missing. This conclusion is supported by the fact that our blue and red early-type dwarfs have comparable total masses (Fig. 6) and, reasonably, central potential wells.

#### 4.3 Dust attenuation

Giant elliptical and lenticular galaxies have been known to contain dust since a long time, thanks to catalogues of far-IR emission (Jura 1986; Bally & Thronson 1989; Knapp et al. 1989; Roberts et al. 1991), extensive visual surveys for dust obscuration (e.g. Hawarden et al. 1981; Ebneter & Balick 1985; Sparks et al. 1985; Kim 1989) and the discovery

of atomic and molecular line emission (e.g. Sage & Wrobel 1989; Thronson, Bally & Hacking 1989; Wiklund & Henkel 1989; Gordon 1990; Roberts et al. 1991; Lees et al. 1991). Michard (1998) noted that dust patterns are more common and important in disk ellipticals than in boxy ones. Recently atomic line emission has been detected in early-type dwarfs (e.g. Young & Lo 1997), as well as dust signatures (Elmegreen et al. 2000). The latter discovery is particularly relevant to this study since it involves a dE,N galaxy of the Virgo cluster (VCC 882). It supports the hypothesis that color gradients and distribution in  $r_{eB}/r_{eH}$  of our early-type dwarfs are due to differences in optical depth (i.e. dust column density) and/or dust geometry among individual objects (Witt, Thronson & Capuano 1992). As Witt, Thronson & Capuano point out, the geometry of the dust distribution with respect to stars has an important role, due to the importance exercised on scattering and on the determination of the relative fraction of stars which are lightly obscured. For one plausible geometry, these authors find that the maximum reddening occurs at intermediate optical depths, while both very small and very large amounts of dust produce almost neutral broad-band colors. Transfer of radiation through a dusty medium with an optical depth  $\tau_V$  of the order of 1 is able to reproduce some color and surface brightness variations in giant elliptical galaxies that are usually attributed to age/metallicity gradients of the stellar populations.

According to the results of Witt, Thronson & Capuano, no relationship of the dust-induced increase of  $r_{eB}/r_{eH}$  with B–H must be expected a priori, so that the trend in Fig. 2 might be due simply to chance. On the other hand, since dust production is a result of star formation, relatively larger amounts of dust may be associated with galaxies of intrinsic blue colors. In addition, a necessary condition for retention of metals in dwarf stellar systems (Legrand et al. 2001), despite their higher sensitivity to galactic winds than giant ones (Arimoto & Yoshii 1987), seems to be the presence of a diffuse gaseous halo (D’Ercole & Brighenti 1999; Silich & Tenorio-Tagle 2001). The hint that the maximum HI content allowed by observations increases in bluer objects (cf. Sect. 4.1) may suggest that a greater part of the metals (and of the dust) was retained by the relatively HI-rich and bluer early-type dwarfs of our sample. This may explain the trend of  $r_{eB}/r_{eH}$  with B–H in Fig. 2.

With the caveat of large observational uncertainties, Fig. 8 suggests a stronger effect of dust attenuation in the blue early-type dwarfs than in most of the giant E and S0 galaxies. This may sound at odd with the metal-richness of early-type giants with respect to dE and dS0 galaxies (cf. Yoshii & Arimoto 1987), commonly interpreted with the galactic-wind model of Arimoto & Yoshii (1987). The interpretation of Fig. 8 in terms of dust content and distribution is complex enough to deserve a quantitative investigation of the effect of dust attenuation on the photometric properties on both giant and dwarf E and S0 galaxies in a future paper.

## 5 CONCLUSIONS

Thanks to the surface photometry of 18 Virgo cluster dwarf elliptical (dE) and dwarf lenticular (dS0) galaxies, made by Gavazzi et al. (2001) in the H-band ( $1.65 \mu\text{m}$ ) and in the

B-band ( $0.44 \mu\text{m}$ ), we are able to study the wavelength-dependence of their effective radii.

We find that the ratio of the effective radii of these stellar systems in these two spectral pass-bands,  $r_{eB}/r_{eH}$ , ranges between 0.7 and 2.2.  $r_{eB}/r_{eH}$  does not depend on the bulge-to-total light ratio or total mass but on the total color index B–H. In fact, dwarf ellipticals and lenticulars with a red total color index B–H (i.e. with  $3.2 < B-H < 4$ ) have equal effective radii in the B and H pass-bands. By contrast, blue (i.e. with  $2.5 < B-H < 3.1$ ) dEs and dS0s have B-band effective radii about 50% longer than the H-band ones, on average. Consistently, strong negative color gradients are present only in the B–H color profiles of the blue dwarfs of our sample.

The trend of increasing  $r_{eB}/r_{eH}$  with bluer B–H is not confirmed by a reference sample of 29 well-studied Coma cluster giant E and S0 galaxies, which span a narrow range in color ( $3.3 < B-H < 4.2$ ). For these early-type giants,  $r_{eB}/r_{eH}$  spans a broad range (0.2–2.2) and has a mean value of  $\sim 1.1$ . The origin of the wavelength-dependence of the effective radii in these stellar systems (e.g.: age/metallicity gradient along the radial coordinate and dust attenuation) does not imply a consistent trend of  $r_{eB}/r_{eH}$  with B–H.

Assuming each of these three distinct interpretations of the origin of color gradients, we discuss the origin of the association of strong negative color gradients with blue colors found in the early-type dwarfs under study, in relation with current scenarios of formation and evolution of dE and dS0 galaxies.

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